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Attorney Docket No. 5000.301
Confirmation No. 6091

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: David P. Malta et al.
Serial No. 10/628,189
Filed: July 28, 2003
For: GROWTH OF ULTRA-HIGH PURITY SILICON CARBIDE CRYSTALS IN AN AMBIENT CONTAINING HYDROGEN

Group Art Unit: 1765

February 23, 2005

MAIL STOP PGPUB
Commissioner for Patents
Alexandria, VA 22313-1450

REQUEST FOR A CORRECTED PATENT APPLICATION PUBLICATION UNDER 37 C.F.R. § 1.221(B)

Sir:

Pursuant to 37 C.F.R. § 1.221(b), Applicant's hereby request republication of the above-referenced patent application to correct a material mistake on the part of the U.S. Patent and Trademark Office (USPTO). This request is made within two months of the date of the patent application publication.

U.S. Application Serial No. 10/628,189 (the '189 application) published as United States Patent Application Publication No. 2005/0022724 (the '724 publication) on February 3, 2005. The specification of the '724 publication, however, is not the specification of the '189 application as filed.

Applicants accordingly respectfully request that the USPTO republish the '189 application with the correct specification.

In support of the request, attached hereto are copies of the following:

1) the specification of Serial No. 10/628,189 as filed;
2) the utility patent application transmittal form;
3) the return postcard date stamped by the USPTO; and
4) U.S. Patent Application Publication 2005/0022724.

It is believed that no additional fees are due in conjunction with the filing of this request. If, however, it is determined that fees are due, authorization is hereby given to deduct such fees from Deposit Account No. 50-0332.

Respectfully submitted,

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Date Mailed: July 28, 2003
Attorney Docket No. 5000.301

Kindly acknowledge receipt of the accompanying Utility Patent Application with Application Transmittal Cover Sheet for:
Inventor(s): George Fechko et al.; Title of Invention: GROWTH OF ULTRA-HIGH PURITY SILICON CARBIDE CRYSTALS IN AN AMBIENT CONTAINING HYDROGEN
Pages of Spec. (including claims and abstract) 25; No. of Claims 42
No. of Drawing Sheets 2; Declaration w/ Power of Attorney Enclosed ___(___pages)
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	5000.301
First Inventor	George Fechko et al.
Title	Growth of Ultra-High Purity Silicon Carbide Crystals in an Ambient Containing Hydrogen
Express Mail Label No.	EV315198492US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
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Washington, DC 20231

1. [✔] Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)
2. [ ] Applicant claims small entity status. See 37 CFR 1.27.
3. [✔] Specification [*Total Pages* 25]
(preferred arrangement set forth below)
   - Descriptive title of the invention
   - Cross Reference to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to sequence listing, a table, or a computer program listing appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings (*if filed*)
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. [✔] Drawing(s) *(35 U.S.C. 113)* [*Total Sheets* 2]
5. Oath or Declaration [*Total Pages*]
   a. [ ] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 CFR 1.63 (d))
   (for continuation/divisional with Box 18 completed)
      i. [ ] DELETION OF INVENTOR(S)
      Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. [ ] Application Data Sheet. See 37 CFR 1.76
7. [ ] CD-ROM or CD-R in duplicate, large table or Computer Program (*Appendix*)
8. Nucleotide and/or Amino Acid Sequence Submission (*if applicable, all necessary*)
   a. [ ] Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. [ ] CD-ROM or CD-R (2 copies); or
      ii. [ ] paper
   c. [ ] Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. [ ] Assignment Papers (cover sheet & document(s))
10. [ ] 37 CFR 3.73(b) Statement *(when there is an assignee)* [ ] Power of Attorney
11. [ ] English Translation Document *(if applicable)*
12. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
13. [ ] Preliminary Amendment
14. [✔] Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
15. [ ] Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. [ ] Nonpublication Request under 35 U.S.C. 122 (b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.
17. [ ] Other: ....

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No.:________/__________

Prior application information: *Examiner:*______________________ *Group Art Unit:* __________

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

19. CORRESPONDENCE ADDRESS

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Signature	[signature]	*Date*	7/28/2003

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Growth of Ultra-High Purity Silicon Carbide Crystals in an Ambient Containing Hydrogen

STATEMENT OF GOVERNMENT INTEREST

[0001] The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of Contract No. N00014-02-C-0306 awarded by Defense Advanced Research Projects Agency (DARPA).

BACKGROUND OF THE INVENTION

[0002] This application is related to copending application Serial No. _______, filed concurrently herewith for, "Reducing Nitrogen Content in Silicon Carbide Crystals by Sublimation Growth in a Hydrogen Containing Ambient."

[0003] The present invention relates to the growth of ultra high purity semi-insulating silicon carbide crystals in a hydrogen ambient that yields a low nitrogen concentration in the crystal to enhance the semi-insulating qualities.

[0004] Silicon carbide (SiC) has a combination of electrical and physical properties that make it an attractive semiconductor material for high temperature, high voltage, high frequency and high power electronic devices. These properties include a 3.0 electron-volt (eV) bandgap (6H), a 4 Megavolt per centimeter (MV/cm) electric field breakdown, a 4.9 W/cmK thermal conductivity, and a 2×10^7 centimeter per second (cm/s) electron drift velocity. Silicon carbide is also particularly useful in its ability to be made conductive by doping or semi-insulating by various processing techniques. These qualities make silicon carbide a material of choice for a vast array of electronic applications.

[0005] The production of integrated circuits for many applications, such as RF devices, requires a semi-insulating substrate on which electronic devices can be built and connected to one another. Historically, sapphire was used as substrate material for

microwave devices because of its high resistance to current flow. Sapphire has the disadvantage, however, of limiting the types of semiconductor layers that may be fabricated on the substrate with appropriate crystal lattice matching for proper device operation.

[0006] As recognized by those familiar with semiconductor electronics, certain devices often require high resistivity ("semi-insulating") substrates to reduce RF coupling or for other functional purposes such as device isolation because conductive substrates tend to cause significant problems at higher frequencies. As used herein, the terms "high resistivity" and "semi-insulating" can be considered synonymous for most purposes. In general, both terms describe a semiconductor material having a resistivity greater than about 1500 ohm-centimeters (ohm-cm).

[0007] In general, semi-insulating silicon carbide devices should have a substrate resistivity of at least 1500 ohm-centimeters (ohm-cm) in order to achieve RF passive behavior. Furthermore, resistivities of 5000 ohm-cm or better are needed to minimize device transmission line losses to an acceptable level of 0.1 dB/cm or less. For device isolation and to minimize back-gating effects, the resistivity of semi-insulating silicon carbide should approach a range of 50,000 ohm-cm or higher.

[0008] Research in the field shows that the semi-insulating behavior of a silicon carbide substrate is the result of energy levels deep within the band gap of the silicon carbide; i.e., farther from both the valence band and the conduction band than the energy levels created by p-type and n- type dopants. These "deep" energy levels are believed to consist of states lying at least 300 meV away from the conduction or valence band edges, e.g., U.S. Pat. No. 5,611,955 which is representative of standard prior research in this art.

[0009] Various devices fabricated in silicon carbide require different degrees of conductivity to provide accurate electrical responses, such as current switching, signal amplification, power transfer, etc. In fact, the desired electrical response of a silicon carbide crystal can range from a highly conductive crystal to a highly resistive (semi-insulating) crystal. Silicon carbide grown by most techniques is generally too conductive for semi-insulating purposes, however. In particular, the nominal or unintentional

nitrogen concentration in silicon carbide tends to be high enough in sublimation grown crystals ($\geq$ 1-2 x $10^{17}/cm^3$) to provide sufficient conductivity to prevent silicon carbide from being used in devices that require a semi-insulating substrate, such as microwave devices.

[0010] A recurring issue in fabricating silicon carbide crystals for electronic devices, therefore, is the control of elemental impurities such as nitrogen within the crystal. Nitrogen content, for example, affects the color of a silicon carbide crystal. This color change can have deleterious consequences for the usefulness of a crystal in certain applications requiring luminescence, such as light emitting diodes and gemstone fabrication. The nitrogen in a crystal may also yield electrical conductivity that must be controlled for silicon carbide to have appropriate properties in diverse electronic applications. The invention herein includes a means for achieving a semi-insulating silicon carbide crystal one step of which comprises reducing the nitrogen content, and therefore the inherent conductivity of a crystal with an improved method of sublimation growth in a hydrogen ambient atmosphere.

[0011] Researchers, therefore, persistently struggle with the issue of controlling, and particularly reducing, the amount of nitrogen that is transferred from the atmosphere of a sublimation growth chamber into a growing silicon carbide crystal. Commonly assigned U.S. Patent No. 5,718,760 to Carter et al., for example, discloses a method of reducing the nitrogen concentration in the ambient atmosphere of a silicon carbide sublimation system. The Carter '760 patent reduces the nitrogen by back filling the growth chamber with an inert gas such as argon and then evacuating the growth chamber to a very low pressure.

[0012] Another technique for decreasing the ambient nitrogen in a crystal growth system is the minimization of nitrogen content in the equipment itself. Commonly assigned U.S. Patent No. 5,119,540 issued to Kong et al., discloses that most, if not all, of the undesired nitrogen in a crystal growth system is a result of nitrogen gas that escapes from the equipment itself. For example, nitrogen trapped in graphite equipment may leak into the ambient atmosphere because the equipment cracks or develops pin holes through

which nitrogen escapes at very high temperatures. The Kong '540 patent prevents incorporation of nitrogen into subject silicon carbide crystals by utilizing fabrication equipment made of materials with low nitrogen concentration. The Kong '540 patent, therefore, teaches that extremely pure equipment components that are free of high nitrogen content result in silicon carbide crystals that are less contaminated with undesirable levels of nitrogen. Kong '540 shows nitrogen minimization in a chemical vapor deposition system but is equally pertinent in the sublimation systems discussed herein.

[0013] In addition to reducing the concentration of nitrogen, researchers also reduce the effects of unavoidable nitrogen content within a silicon carbide crystal. For example, the Carter '760 patent acknowledges that the background nitrogen in the sublimation chamber can lead to undesirable crystal color. The '760 patent, therefore, discloses a method of compensating the nitrogen content with a corresponding p-type dopant to minimize or eliminate the undesirable effects of the nitrogen. The p-type dopant and the nitrogen compensate one another and prevent undesirable color centers in the preferably colorless silicon carbide crystal of the Carter '760 invention.

[0014] The nitrogen compensation technique has also been used to prevent unintentional nitrogen doping from dominating the conductivity of silicon carbide crystals. Commonly assigned U.S. Patent No. 6,218,680, also issued to Carter et al., discloses a further method of compensating the nitrogen content of a silicon carbide crystal grown by sublimation. Carter points out that boron may be used to compensate the inherent nitrogen. Carter '680 also utilizes the temperature gradient in the disclosed sublimation process to create point defects in a silicon carbide crystal. The Carter '680 technique pairs an undesirable nitrogen concentration in the silicon carbide crystal with a corresponding acceptor dopant, such as boron. Carter '680 then pairs any excess dopants with temperature induced point defects to yield a desired semi-insulating crystal.

[0015] Other research also concedes that unintentional nitrogen incorporation occurs in silicon carbide crystals grown by sublimation. This research tends to focus on means for minimizing the effects of the undesirable nitrogen concentration instead of preventing

the nitrogen incorporation from the outset. U.S. Patent No. 5,611,955, issued to Barrett et al. is illustrative of this point. Barrett '955 shows a means of introducing elements such as vanadium into the semiconductor material that create deep energy states within the forbidden energy gap. The Barrett '955 method accounts for nitrogen content in a silicon carbide crystal by trapping the nitrogen and hindering electron mobility from the nitrogen. Barrett, therefore, achieves a semi-insulating silicon carbide substrate by adjusting the effects of the nitrogen instead of preventing its presence in the crystal.

[0016] The techniques set forth in the two Carter patents, which have a common assignee as the invention described and claimed herein, are useful for their respective purposes to minimize the effects of nitrogen incorporation in a silicon carbide crystal. The Barrett '955 patent requires further elemental doping and can give rise to unpredictable electrical responses in a subject silicon carbide crystal.

[0017] A need continues to exist, therefore, for a method of gaining extensive control over the incorporation of nitrogen into a silicon carbide crystal at the point of initial sublimation. By controlling the nitrogen content from the initial growth of the crystal, compensation techniques and the associated process steps may be minimized. Controlling the nitrogen incorporation also allows development of more diverse types of crystals, including crystals with varying degrees of nitrogen content for specialized purposes.

[0018] The method described and claimed herein provides a technique for fabricating semi-insulating silicon carbide crystals with a more predictable resistivity than methods of the prior art. Gaining control over the amount of nitrogen incorporated into a silicon carbide crystal grown by sublimation is a critical improvement in sublimation processes and yields a more reliable, higher quality semi-insulating silicon carbide crystal product.

SUMMARY OF THE INVENTION

[0019] The inventors herein have developed a method of producing ultra high purity semi-insulating silicon carbide crystals in a hydrogen or hydrogen-containing ambient that yields a low nitrogen concentration in the crystal to enhance the semi-insulating

qualities. As noted above, standard sublimation growth of silicon carbide often takes place in an argon ambient atmosphere. One of the improvements to sublimation growth of silicon carbide described herein is the replacement of the argon ambient with a hydrogen ambient in the growth chamber. The hydrogen ambient allows control and selective tuning of the nitrogen content of the growing crystal.

[0020] The nitrogen content of a silicon carbide crystal is an instrumental factor in establishing crystal conductivity or resistivity. The method described and claimed herein, therefore, provides a technique for reducing the nitrogen content that is transferred from the ambient atmosphere of a sublimation growth chamber to a silicon carbide crystal grown therein. The reduced nitrogen content in the growing crystal provides a more reliable semi-insulating quality to the resulting silicon carbide product.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Figure 1 shows the low temperature photoluminescence spectrum corresponding to a 4H-silicon carbide crystal grown in a conventional argon ambient of the prior art.

[0022] Figure 2 shows the low temperature photoluminescence spectrum corresponding to a 4H-silicon carbide crystal grown in a hydrogen ambient according to the invention herein.

DETAILED DESCRIPTION

[0023] The invention herein is a method of reducing the nitrogen content of a semi-insulating silicon carbide crystal grown by sublimation and a resulting high purity semi-insulating silicon carbide crystal with a reduced nitrogen concentration therein. A first embodiment of the invention introduces a hydrogen or hydrogen-containing ambient atmosphere into a sublimation growth chamber used to grow silicon carbide crystals. Previously standard sublimation systems utilize an argon ambient in the growth of silicon carbide. The inventors herein have discovered that a hydrogen ambient is more useful than other ambient gases to control the nitrogen content of the growing crystal.

[0024] The method of the invention herein includes introducing a silicon carbide source powder and a silicon carbide seed crystal into a sublimation growth chamber. The source powder, as its name implies, provides a source of silicon carbide species in the growth chamber for growing a silicon carbide crystal on a growth surface provided by the silicon carbide seed crystal. U.S. Patent No. Re. 34,861, the entire contents of which are incorporated by reference herein, sets forth that solid silicon carbide in powdered form is one such preferred source material. The method of the first embodiment includes heating the silicon carbide source powder to sublimation in a hydrogen ambient growth chamber. The hydrogen ambient of the sublimation growth chamber is established by introducing hydrogen gas into the growth chamber at a pressure of between about 0.1 and 50 Torr and at a flow rate of between about 10 and 1000 standard cubic centimeters per minute (sccm).

[0025] The sublimation process requires temperature control of different regions within the growth chamber. While heating the silicon carbide source powder to a first temperature, the silicon carbide seed crystal is heated and maintained at a second temperature approaching the temperature of the source powder. The temperature of the seed crystal is, therefore, lower than the temperature of the source powder and lower than that temperature at which silicon carbide will sublime. The reduced seed crystal temperature encourages sublimed species from the source powder to condense upon the seed crystal. The seed crystal, therefore, provides the growth surface for fabricating a silicon carbide crystal with desired dimensions. The method herein includes a continued heating of the silicon carbide source powder until a desired amount of silicon carbide crystal growth has occurred upon the seed crystal.

[0026] The seed crystal preferably has a polytype selected from among the 3C, 4H, 6H and 15R polytypes of silicon carbide, depending on the polytype desired in the resulting grown crystal. The silicon carbide species that condense onto the seed crystal optimally grow a silicon carbide crystal with the same polytype as the seed crystal.

[0027] The invention maintains a thermal gradient between the growth surface of the seed crystal and the source powder. Re. 34,861 describes various means for maintaining a thermal gradient between the source powder and the seed crystal. The gradient may be accomplished, for example, by establishing a desired geometric distance and temperature difference between the seed crystal and the source powder. Otherwise, the temperature gradient may be established by independently controlling the temperatures of the respective regions within the growth chamber in which the silicon carbide powder sublimes and the silicon carbide crystal grows.

[0028] Typically, the silicon carbide source powder is maintained at a temperature of between about 2000°C and 2500°C. The seed crystal, in turn, is maintained at a temperature of between about 50°C and 350°C lower than the temperature of the source powder.

[0029] The method herein further includes maintaining the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal. The point defects, in conjunction with lower nitrogen content, render the resulting silicon carbide crystal semi-insulating.

[0030] Alternatively, the step of increasing the number of point defects can comprise the method described in co-pending and commonly-assigned U.S. application No. 10/064,232, filed June 24, 2002 for, "Method For Producing Semi-Insulating Resistivity In High Purity Silicon Carbide Crystals," the contents of which are incorporated entirely herein by reference. As set forth therein, the method comprises heating a silicon carbide crystal to a temperature above the temperatures required for CVD growth of silicon carbide from source gases, but less than the temperatures at which disadvantageously high rates of silicon carbide sublimation occur under the ambient conditions to thereby thermodynamically increase the concentration (i.e., number per unit volume) of point defects and resulting states in the crystal; and then cooling the heated crystal to approach room temperature at a sufficiently rapid rate to minimize the time spent in the temperature range in which the defects are sufficiently mobile to disappear or be re-

annealed into the crystal to thereby produce a silicon carbide crystal with a concentration of point defect states that is greater than the concentration of point defect states in an otherwise identically grown silicon carbide crystal that has not been heated and cooled in this manner.

[0031] The method described and claimed herein allows the production of semi-insulating silicon carbide crystals without the need for deep level doping elements, such as vanadium. As discussed in commonly assigned U.S. Patent No. 6,218,680, prior art methods of fabricating semi-insulating silicon carbide incorporate dopants that form energy states at levels between the valence and conduction bands of silicon carbide. These energy states of the prior art are far removed from both the conduction band and the valence band to enhance the semi-insulating qualities of the crystal. Common deep level trapping elements incorporated into silicon carbide include vanadium and other transition metals. The method herein allows the fabrication of semi-insulating silicon carbide crystals without relying upon more complicated doping levels that may be quite difficult to accurately control.

[0032] The method developed by the inventors herein allows for deep level trapping elements in the silicon carbide source powder to be kept to minimum levels, thereby simplifying the fabrication process. The deep level trapping elements in the silicon carbide source powder are referred to herein as being present in amounts that are "below detectable levels," meaning that the elements are present in amounts that cannot be detected by modern sophisticated analytical techniques.

[0033] In particular, because one of the more common techniques for detecting elements in small amounts is secondary ion mass spectroscopy ("SIMS"), the detectable limits referred to herein are those amounts of elements such as vanadium and other transition metals that are present in amounts less than 1×10^{16} (1E16), or in other cases (including vanadium), less than 1E14. These two amounts represent typical detection limits for most trace elements (particularly vanadium) using SIMS techniques; e.g., SIMS Theory—Sensitivity and Detection Limits, Charles Evans & Associates (1995), www.cea.com.

[0034] The method described and claimed herein helps control the amount of nitrogen incorporated into the growing silicon carbide crystal by controlling the hydrogen concentration in the ambient atmosphere of the growth chamber. Although the inventors do not wish to be bound by any particular theory, the effectiveness of the hydrogen on suppressing the nitrogen in the crystal is attributed to the passivation of the silicon carbide growth surface by hydrogen atoms. The hydrogen atoms, in effect, block, reduce, or otherwise hinder the incorporation of nitrogen atoms at the surface of the growing crystal.

[0035] The method of the invention herein, therefore, is appropriately described in another embodiment as a method of passivating a growing silicon carbide crystal in a sublimation growth chamber to control the nitrogen that can be incorporated into the crystal. A second embodiment of the invented method includes introducing an ambient gas containing hydrogen into the growth chamber and heating a silicon carbide source powder to sublimation in the hydrogen ambient growth chamber. The source powder is heated while simultaneously heating and maintaining a silicon carbide seed crystal in the hydrogen ambient growth chamber to a second temperature below the temperature of the source powder. The temperature of the seed crystal is low enough for sublimed species from the source powder to condense upon the seed crystal.

[0036] The hydrogen passivation method, furthermore, maintains the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal. The point defects assist in rendering the resulting silicon carbide crystal semi-insulating. The heating, sublimation, and condensation steps continue at sufficiently high temperatures to induce a sufficient number of point defects for a semi-insulating crystal. The overall silicon carbide deposition continues until a desired amount of highly pure semi-insulating silicon carbide crystal grows upon the seed crystal.

[0037] An ambient concentration of hydrogen is maintained in the growth chamber sufficient to passivate the growing silicon carbide crystal against the incorporation of nitrogen. The hydrogen passivation thereby controls the amount of nitrogen incorporated

into the growing silicon carbide crystal. The inventors do not wish to be bound by any particular theory, but research in the field of sublimation grown silicon carbide crystals suggests that the hydrogen atoms in the ambient atmosphere of the growth chamber reduce the number of unpaired electrons in the silicon carbide crystal. U.S. Patent No. 5,151,384, issued to Williams and incorporated by reference herein, describes and claims the electron pairing of hydrogen passivation on silicon compounds at column 2, lines 38–70. This reduction of unpaired electrons corresponds to a reduced number of nitrogen atoms likely to bond with the silicon carbide crystal as it grows.

[0038] Alternative explanations also exist to explain the physical mechanism by which the hydrogen ambient suppresses nitrogen incorporation. One explanation is that the hydrogen passivation of the silicon carbide crystal is essentially a layer of hydrogen atoms on the crystal growth surface that protects the surface from nitrogen incorporation. See, e.g. U.S. Patent No. 5,709,745 (col. 26, lines 18–24); U.S. Patent No. 6,113,451 (col. 8, lines 38–44); and U.S. Patent No. 6,201,342 (col. 8, lines 33–39), all of which are incorporated entirely by reference herein.

[0039] Finally, published European Patent Application 0561462A2 (col. 10, lines 42–48) filed on March 12, 1993 describes hydrogen passivation as filling in spaces between the silicon carbide crystal grain boundaries and disallowing nitrogen incorporation therein. The inventors do not rely on any particular one of these descriptions of the effects of hydrogen in silicon carbide growth. The method disclosed and claimed herein successfully controls nitrogen content by a combination of these physical and chemical interactions between the hydrogen atoms and the growing silicon carbide crystal. The method results in a desirable highly pure, semi-insulating silicon carbide crystal growth.

[0040] Controlling the hydrogen flow rate into the growth chamber between about 80 and 1000 standard cubic centimeters per minute (sccm) at a pressure of between about 0.1 and 50 Torr provides a sufficient hydrogen concentration in the growth chamber to yield the desired crystal. The method has proven successful in fabricating a silicon carbide crystal with less than about 2×10^{15} nitrogen atoms per cubic centimeter (cm^{-3}). In preferred practice, the hydrogen concentration in the ambient atmosphere yields a

silicon carbide crystal with less than about 1×10^{15} cm^{-3} nitrogen atoms. The low nitrogen concentration of the resulting silicon carbide crystals, coupled with the deep levels, yields a resistivity greater than or equal to 1×10^5 ohm-cm.

[0041] The invention claimed herein is useful in a variety of other applications. For example, synthesizing high purity silicon carbide powder in a hydrogen containing environment potentially reduces nitrogen content in the source powder. The technique is also useful in the manufacture of near colorless gemstone material. Finally, the control of nitrogen incorporation in a silicon carbide crystal represents an advancement in the manufacture of semi-insulating crystals and wafers of silicon carbide used in the manufacture of MESFET and HEMT high frequency electronic devices. The technique disclosed herein provides an efficient and straight forward method of achieving extremely low nitrogen levels in silicon carbide crystals and wafers. In fact, bulk wafers having extremely low concentrations of nitrogen may be produced by controlling the nitrogen content of a growing crystal. Wafers made from these crystals may displace the need for the thick high purity epitaxial layers grown on current silicon carbide substrates.

[0042] Figures 1 and 2 illustrate that the invention described and claimed herein presents a significant advancement in the field of growing highly pure, semi-insulating silicon carbide crystals by sublimation. The hydrogen ambient controls the nitrogen incorporated into the crystal and provides a more reliable semi-insulating silicon carbide crystal quality. Figure 1 shows the low temperature photoluminescence spectrum corresponding to a 4H-silicon carbide crystal grown in a conventional argon ambient. Figure 2 shows the low temperature photoluminescence spectrum corresponding to a 4H-silicon carbide crystal grown in a hydrogen ambient according to the invention herein.

[0043] A background discussion is helpful in understanding the advantages illustrated by Figures 1 and 2. The figures plot the photoluminescence spectra for silicon carbide crystals and show luminescent intensity peaks at specific wavelengths. These peaks of luminescence are proportionally related to the nitrogen content of the silicon carbide crystal under consideration. See Ivanov et al., Nitrogen Doping Concentration as determined by Photoluminescence in 4H- and 6H- SiC, Journal of Applied Physics, vol.

80, no. 6, September 15, 1996, pp. 3504–3508. The nitrogen concentration in a crystal can be determined by the luminescence of electrons and holes during their recombination at neutral nitrogen centers.

[0044] In the study of electron-hole recombinations, silicon carbide is known as an indirect bandgap semiconductor. As known to those familiar with electronic transitions, a direct transition occurs in a semiconductor when the valence band maxima and the conduction band minima have the same momentum state. This means that crystal momentum is readily conserved during recombination of electrons and holes so that the energy produced by the transition can go predominantly and efficiently into the photon, (i.e., to produce light rather than heat). When the conduction band minimum and valence band maximum do not have the same momentum state, a phonon (i.e., a quantum of vibrational energy) is required to conserve crystal momentum and the transition is called "indirect." The necessity of a third particle, the phonon, makes indirect radiative transitions less likely, thereby reducing the light emitting efficiency of the crystal.

[0045] The indirect band gap of silicon carbide prevents the direct recombination of holes and electrons. The direct non-phonon assisted recombination of a free exciton, independent of other particles, is therefore forbidden. The recombination of electrons and holes in silicon carbide requires the formation of the previously discussed phonon to account for the difference in momentum between recombined electrons and holes.

[0046] Ivanov et al. reported in 1996 that the electron-hole exciton may be coupled to a phonon or bound to an impurity in the crystal to account for the required conservation of momentum. The luminescence intensity of the recombination is dependent upon whether the recombined electron-hole pair is bound to a phonon or to an impurity, such as nitrogen. See Ivanov et al., supra., pp. 3504–3508. Ivanov et al., therefore, show that the concentration of impurity in a crystal can be determined by comparing the luminescence intensity of an electron-hole recombination paired with an impurity and the luminescence intensity of an electron-hole recombination paired with a phonon.

[0047] Figures 1 and 2 herein illustrate these concepts and show the success of the nitrogen reduction method of the present invention. The figures plot the relative luminescence intensity versus wavelength for 4H silicon carbide crystals. The peak luminescence intensity is shown as Q_0 and corresponds to the intensity of an electron-hole recombination bound to a nitrogen atom as an impurity in the crystal. Less intense peaks of luminescence in the figures correspond to phonon coupled recombinations, the most significant of which for purposes herein is the recombination marked I_{75}. I_{75} is the highest intensity phonon-assisted recombination and can be identified by its asymmetric line shape (Ivanov, supra at 3505). As known to those in the art, the ratio of Q_0 to I_{75} yields a constant that can be used to extrapolate the nitrogen content of the subject silicon carbide crystal (Ivanov, supra at 3508).

[0048] Considering Figure 1, the luminescence intensity is plotted for a 4H silicon carbide crystal grown by sublimation in a traditional argon ambient atmosphere. Figure 1 is, therefore, indicative of prior art in the area of silicon carbide grown by sublimation. The extrapolated nitrogen content is approximately 3×10^{15} nitrogen atoms per cubic centimeter of the resulting silicon carbide crystal.

[0049] Figure 2 shows the luminescence data corresponding to a crystal grown in a hydrogen ambient atmosphere by the invention disclosed herein. As can be seen in the spectrum, the ratio of Q_0 to I_{75} is at 0.6, corresponding to a nitrogen concentration in the crystal of 3×10^{14} nitrogen atoms per cubic centimeter. The data of Figure 2 shows that the presence of a hydrogen ambient in the sublimation growth chamber reduced the nitrogen content in the crystal by approximately one order of magnitude. Figure 2 shows, therefore, that the hydrogen concentration in the growth chamber ambient can be used to reduce the nitrogen content of the resulting silicon carbide crystal grown therein. The resulting low nitrogen crystal is a high purity semi-insulating crystal as desired.

[0050] In the specification, there have been disclosed typical embodiments of the invention, and, although specific terms have been employed, they have been used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

THAT WHICH IS CLAIMED IS:

1. A method of producing a semi-insulating silicon carbide crystal with a controlled nitrogen content, the method comprising:

introducing an ambient gas containing hydrogen into a sublimation growth chamber;

heating a silicon carbide source powder to sublimation in the hydrogen ambient growth chamber while,

heating and then maintaining a silicon carbide seed crystal in the hydrogen ambient growth chamber to a second temperature below the temperature of the source powder, at which second temperature sublimed species from the source powder will condense upon the seed crystal,

continuing to heat the silicon carbide source powder until a desired amount of silicon carbide crystal growth has occurred upon the seed crystal;

while maintaining an ambient concentration of hydrogen in the growth chamber sufficient to minimize the amount of nitrogen incorporated into the growing silicon carbide crystal; and

heating the crystal to increase the number of point defects in the crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

2. A method according to Claim 1 wherein the step of heating the crystal to increase the number of point defects comprises maintaining the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

3. A method according to Claim 1 wherein the step of heating the crystal to increase the number of point defects comprises heating a silicon carbide crystal to a temperature above the temperatures required for CVD growth of silicon carbide from source gases, but less than the temperatures at which disadvantageously high rates of silicon carbide sublimation occur under the ambient conditions to thereby thermodynamically increase the concentration of point defects and resulting states in the crystal; and then cooling the heated crystal to approach room temperature at a sufficiently rapid rate to minimize the time spent in the temperature range in which the defects are sufficiently mobile to disappear or be re-annealed into the crystal to thereby produce a silicon carbide crystal with a concentration of point defect states that is greater than the concentration of point defect states in an otherwise identically grown silicon carbide crystal that has not been heated and cooled in this manner.

4. A method according to Claim 1 comprising introducing the ambient hydrogen into the growth chamber at a pressure between about 0.1 and 50 Torr.

5. A method according to Claim 1 comprising introducing the ambient hydrogen into the growth chamber at a flow rate of between about 10 and 1000 standard cubic centimeters per minute.

6. A method according to Claim 1 comprising heating a seed crystal having a polytype selected from the group consisting of 3C, 4H, 6H, and 15R polytype of silicon carbide.

7. A method according to Claim 1 comprising maintaining the silicon carbide source powder at a temperature of between about 2000°C and 2500°C and maintaining the seed crystal at a temperature that is between about 50°C and 350°C lower than the temperature of the source powder.

8. A method according to Claim 1 comprising heating a silicon carbide source powder in which the amounts of deep level trapping elements in the source powder are below the levels that can be detected by secondary ion mass spectroscopy (SIMS).

9. A method according to Claim 1 comprising introducing a sufficient amount of ambient hydrogen into the growth chamber to yield a growing silicon carbide crystal with less than about 2×10^{15} nitrogen atoms per cubic centimeter.

10. A method according to Claim 1 comprising introducing a sufficient amount of ambient hydrogen into the growth chamber to yield a growing silicon carbide crystal with less than about 1×10^{15} nitrogen atoms per cubic centimeter.

11. A method according to Claim 1 comprising introducing a hydrocarbon species into the growth chamber to establish the hydrogen ambient.

12. A semi-insulating silicon carbide crystal produced by the method of Claim 1 having a concentration of nitrogen atoms less than about 2×10^{15} cm^{-3}.

13. A semi-insulating silicon carbide crystal produced by the method of Claim 1 having a concentration of nitrogen atoms less than about 1×10^{15} cm^{-3}.

14. A semi-insulating silicon carbide crystal produced by the method of Claim 1 having a resistivity of at least 1×10^5 ohm-cm.

15. A method of producing a semi-insulating silicon carbide crystal with a controlled nitrogen content, the method comprising:

introducing an ambient gas containing hydrogen into a sublimation growth chamber;

heating a silicon carbide source powder to sublimation in the hydrogen ambient growth chamber while,

heating and then maintaining a silicon carbide seed crystal in the hydrogen ambient growth chamber to a second temperature below the temperature of the source powder, at which second temperature sublimed species from the source powder will condense upon the seed crystal,

continuing to heat the silicon carbide source powder until a desired amount of silicon carbide crystal growth has occurred upon the seed crystal;

while maintaining an ambient concentration of hydrogen in the growth chamber sufficient to passivate the growing silicon carbide crystal against the incorporation of nitrogen to thereby minimize the amount of nitrogen incorporated into the growing silicon carbide crystal; and

heating the crystal to increase the number of point defects in the crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

16. A method according to Claim 15 wherein the step of heating the crystal to increase the number of point defects comprises maintaining the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

17. A method according to Claim 15 wherein the step of heating the crystal to increase the number of point defects comprises heating a silicon carbide crystal to a temperature above the temperatures required for CVD growth of silicon carbide from source gases, but less than the temperatures at which disadvantageously high rates of silicon carbide sublimation occur under the ambient conditions to thereby thermodynamically increase the concentration of point defects and resulting states in the crystal; and then cooling the heated crystal to approach room temperature at a sufficiently rapid rate to minimize the time spent in the temperature range in which the defects are sufficiently mobile to disappear or be re-annealed into the crystal to thereby produce a silicon carbide crystal with a concentration of point defect states that is greater than the concentration of point defect states in an otherwise identically grown silicon carbide crystal that has not been heated and cooled in this manner.

18. A method according to Claim 15 comprising introducing the ambient hydrogen into the growth chamber at a pressure of between about 0.1 and 50 Torr.

19. A method according to Claim 15 comprising introducing the ambient hydrogen into the growth chamber at a flow rate of between about 10 and 1000 standard cubic centimeters per minute.

20. A method according to Claim 15 comprising maintaining the silicon carbide source powder at a temperature of between about 2000°C and 2500°C and maintaining the seed crystal at a temperature that is between about 50°C and 350°C lower than the temperature of the source powder.

21. A method according to Claim 15 comprising heating a seed crystal having a polytype selected from the group consisting of 3C, 4H, 6H, and 15R polytype of silicon carbide.

22. A method according to Claim 15 comprising heating a silicon carbide source powder in which the amounts of deep level trapping elements in the source powder are below the levels that can be detected by secondary ion mass spectroscopy (SIMS).

23. A method according to Claim 15 comprising introducing a sufficient amount of ambient hydrogen into the growth chamber to yield a growing silicon carbide crystal with less than about 2×10^{15} nitrogen atoms per cubic centimeter.

24. A method according to Claim 15 comprising introducing a sufficient amount of ambient hydrogen into the growth chamber to yield a growing silicon carbide crystal with less than about 1×10^{15} nitrogen atoms per cubic centimeter.

25. A semi-insulating silicon carbide crystal produced by the method of Claim 13 having a concentration of nitrogen atoms less than about 2×10^{15} cm^{-3}.

26. A semi-insulating silicon carbide crystal produced by the method of Claim 15 having a concentration of nitrogen atoms less than about 1×10^{15} cm^{-3}.

27. A semi-insulating silicon carbide crystal produced by the method of Claim 15 having a resistivity of at least $1 \text{ X } 10^5$ ohm-cm.

28. A method of producing semi-insulating silicon carbide crystal with a controlled nitrogen content, the method comprising:

heating and maintaining a silicon carbide source powder to sublimation while,

heating and maintaining a silicon carbide seed crystal to a temperature below the temperature of the source powder, at which temperature sublimed species from the source powder condense upon the seed crystal to form a continuously expanding growth surface of silicon carbide crystal;

passivating the silicon carbide growth surface with hydrogen atoms to reduce the incorporation of nitrogen from the ambient atmosphere into a resulting silicon carbide crystal,

heating the crystal to increase the number of point defects in the crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

29. A method according to Claim 28 wherein the step of heating the crystal to increase the number of point defects comprises maintaining the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

30. A method according to Claim 28 wherein the step of heating the crystal to increase the number of point defects comprises heating a silicon carbide crystal to a temperature above the temperatures required for CVD growth of silicon carbide from source gases, but less than the temperatures at which disadvantageously high rates of silicon carbide sublimation occur under the ambient conditions to thereby thermodynamically increase the concentration of point defects and resulting states in the crystal; and then cooling the heated crystal to approach room temperature at a sufficiently rapid rate to minimize the time spent in the temperature range in which the defects are sufficiently mobile to disappear or be re-

annealed into the crystal to thereby produce a silicon carbide crystal with a concentration of point defect states that is greater than the concentration of point defect states in an otherwise identically grown silicon carbide crystal that has not been heated and cooled in this manner.

31. A method according to Claim 28 comprising passivating the growth surface with hydrogen atoms by heating the source crystal and the seed crystal in a hydrogen ambient atmosphere.

32. A method according to Claim 28 comprising passivating the growth surface with hydrogen atoms by adding hydrogen to the ambient atmosphere at a pressure of between about 0.1 and 50 Torr.

33. A method according to Claim 28 comprising passivating the growth surface with hydrogen atoms by adding hydrogen to the ambient atmosphere at a flow rate of between about 10 and 1000 standard cubic centimeters per minute.

34. A method according to Claim 28 comprising maintaining the silicon carbide source at a temperature of between about 2000°C and 2500°C and maintaining the seed crystal at a temperature that is between about 50°C and 350°C lower than the temperature of the source powder.

35. A method according to Claim 28 comprising heating a seed crystal having a polytype selected from the group consisting of 3C, 4H, 6H, and 15R polytype of silicon carbide.

36. A method according to Claim 28 comprising heating to sublimation a silicon carbide source powder in which the amounts of deep level trapping elements in the source powder are below the levels that can be detected by secondary ion mass spectroscopy (SIMS).

37. A method according to Claim 28 comprising introducing a sufficient amount of ambient hydrogen into the growth chamber to yield a growing silicon carbide crystal with less than about 2×10^{15} nitrogen atoms per cubic centimeter.

38. A method according to Claim 28 comprising introducing a sufficient amount of ambient hydrogen into the growth chamber to yield a growing silicon carbide crystal with less than about 1×10^{15} nitrogen atoms per cubic centimeter.

39. A semi-insulating silicon carbide crystal produced by the method of Claim 28 having a concentration of nitrogen atoms less than about 2×10^{15} cm^{-3}.

40. A semi-insulating silicon carbide crystal produced by the method of Claim 28 having a concentration of nitrogen atoms less than about 1×10^{15} cm^{-3}.

41. A semi-insulating silicon carbide crystal produced by the method of Claim 28 having a resistivity of at least $1 \text{ X } 10^{5}$ ohm-cm.

42. A method of producing semi-insulating silicon carbide crystal by heating and maintaining a silicon carbide source powder to sublimation in a growth chamber, while heating and maintaining a silicon carbide seed crystal in the growth chamber to a second temperature below the temperature of the source powder, at which second temperature sublimed species from the source powder condense upon the seed crystal to continuously grow a silicon carbide crystal while maintaining the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal to an amount that renders the resulting silicon carbide crystal semi-insulating, the method comprising maintaining an ambient concentration of hydrogen in the growth chamber sufficient to minimize the amount of nitrogen incorporated into the silicon carbide crystal.

Growth of Ultra-High Purity Silicon Carbide Crystals in an Ambient Containing Hydrogen

ABSTRACT OF THE INVENTION

A method is disclosed for producing semi-insulating silicon carbide crystal with a controlled nitrogen content. The method includes the steps of introducing an ambient gas containing hydrogen into a sublimation growth chamber, heating a silicon carbide source powder to sublimation in the hydrogen ambient growth chamber while, heating and then maintaining a silicon carbide seed crystal in the hydrogen ambient growth chamber to a second temperature below the temperature of the source powder, at which second temperature sublimed species from the source powder will condense upon the seed crystal, continuing to heat the silicon carbide source powder until a desired amount of silicon carbide crystal growth has occurred upon the seed crystal, while maintaining an ambient concentration of hydrogen in the growth chamber sufficient to minimize the amount of nitrogen incorporated into the growing silicon carbide crystal, and while maintaining the source powder and the seed crystal during sublimation growth at respective temperatures high enough to increase the number of point defects in the growing crystal to an amount that renders the resulting silicon carbide crystal semi-insulating.

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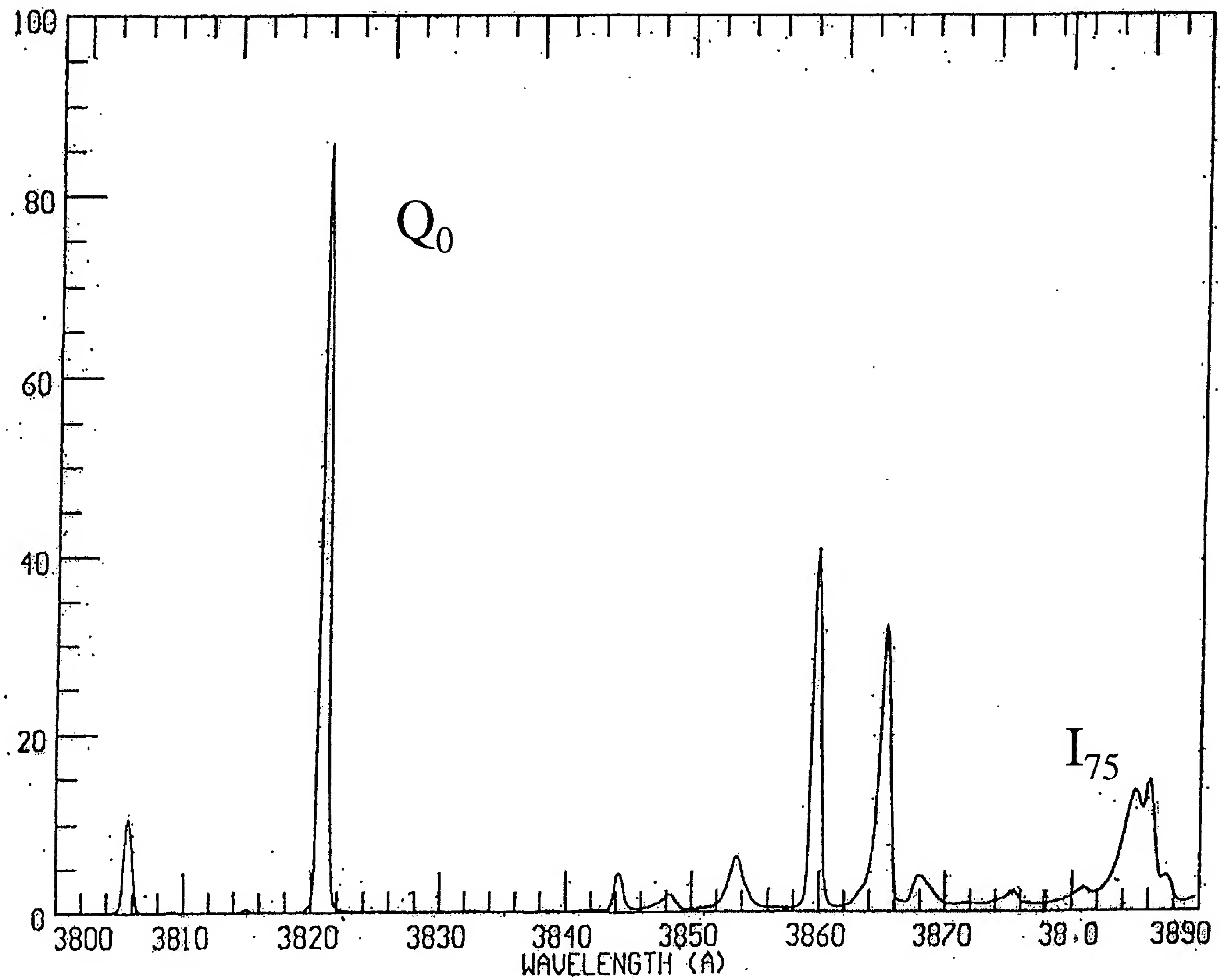
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Figure 1

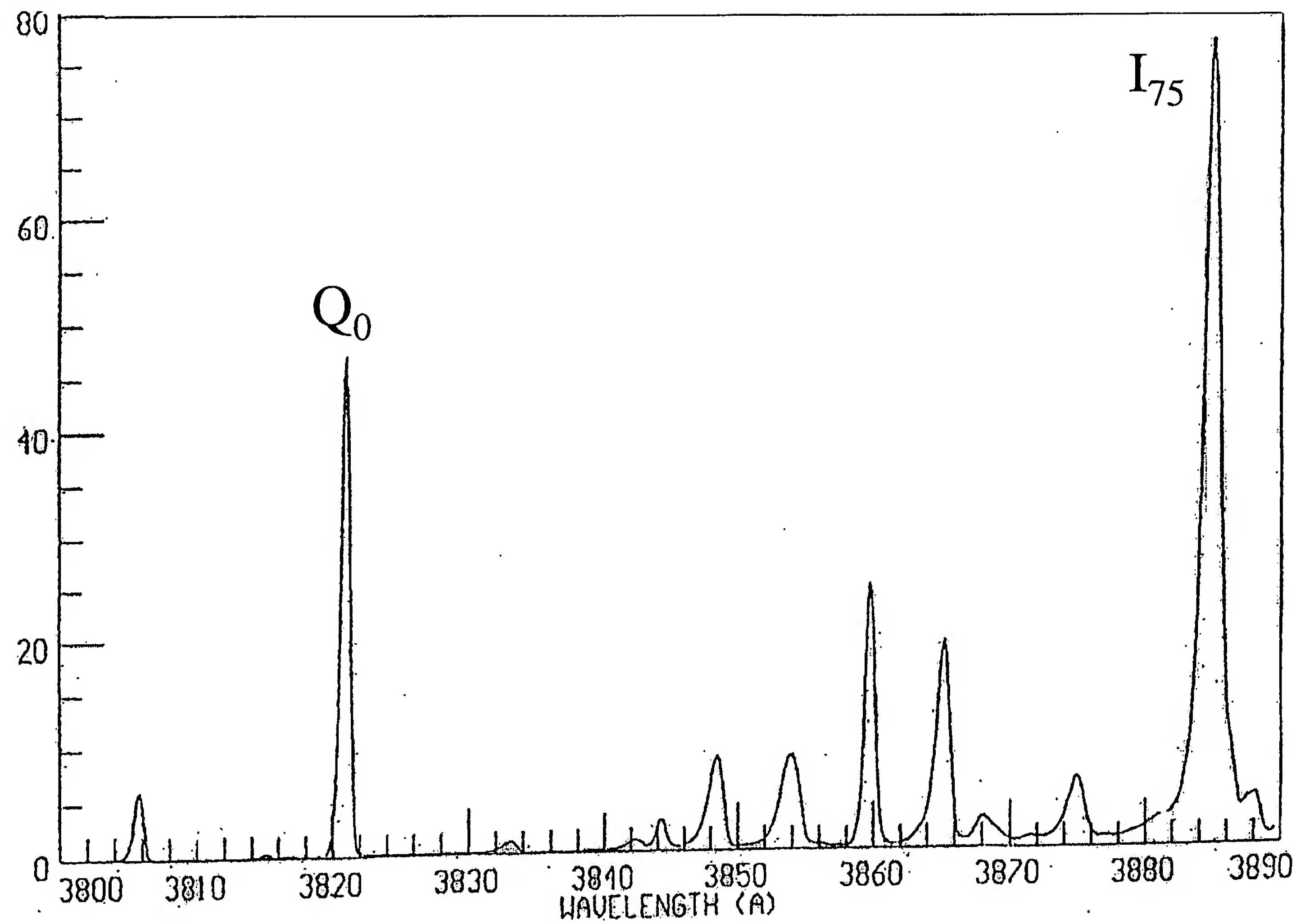
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Figure 2

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(1 of 1)

United States Patent Application *20050022724*
Kind Code **A1**
Malta, David Phillip ; et al. **February 3, 2005**

Growth of ultra-high purity silicon carbide crystals in an ambient containing hydrogen

Abstract

A garment for the transporting, observing, entertaining, training, and displaying of small animals, reptiles and insects (gerbils, mice, snakes, tarantulas, spiders, lizards, etc.) in the tunnels of the garment while on the shoulders of their owners. The garment consists of a see-through, mesh washable fabric panel on top and a brightly colored washable panel underneath, attached to each other using releasable fasteners. The fasteners also provide means to construct tunnel walls and nesting areas for the small animal. The fasteners further provide attachment to the garment tunnel's floor and walls for toys and other paraphernalia to entertain the pet and adorn the garment. This garment allows the owner to hold, observe, and transport his pet without damaging or soiling his clothes while his pet has a tunnel in which to play and rest safely. Also the owner can remove toys, food and nesting material in order to launder the garment.

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Claims

What we claim as our invention is:

1. A body mountable small animal shoulder carrier and toy garment comprising: a top see-through, mesh fabric panel; a bottom brightly colored fabric panel communicating with said top panel at neck opening and outer edges in order to construct tunnel walls within said garment so that a small animal, reptile, insect, etc., can easily be observed, provide adequate circulation and confine it while it is being transported and displayed; a means of releasable attachment, such as releasable fasteners like snaps, hook-loop attachment, etc., of said top panel to bottom panel to close a gap therebetween; a neck opening, said neck opening defined by the area in the center of the garment, creating a left front panel and right front panel to the garment; and wherein said means of releasable attachment provides a means of lateral translation of said left front panel in relation to said right front panel, whereby said neck opening may be adjusted for size by adjustment of said means of lateral translation of said left front panel in relation to said right front panel.

2. The device as defined in claim 1 further comprising: said means of releasable attachments of said top panel and said bottom panel to construct tunnels within the garment cavity produced by the attachment of said top panel to said bottom panel.

3. The device as defined in claim 2 further comprising: a selectable small animal toy from a group of releasably attachable animal toys, said selectable animal toy releasably attachable to tunnel's floor and walls of said garment; and means to releasably attach said selectable animal toy to said garment within the tunnel's floor and walls of said garment.

Description

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Applicant claims priority of Provisional Application No. 60/397,061, filed Jul. 19, 2002

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

[0002] Not Applicable

[0003] REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX

[0004] Not Applicable

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX

[0005] Not Applicable

BACKGROUND OF THE INVENTION

[0006] The invention relates to a garment worn by the user for clothing protection and to transport and entertain small animals (gerbils, mice, snakes, tarantula, spiders, lizards, etc.). More specifically, this garment relates to a short, very colorful shoulder cover garment that is used to protect the clothing of the user and to display, shelter and observe the animal while providing entertainment and protection of the animal.

[0007] Individuals who have small animals (gerbils, mice, snakes, tarantulas, spiders, lizards, etc.) often relate to them closely and like to show them off and play with them out of their cages, often going so far as to put them in a pocket or bag for their protection. Around the shoulders is a natural place for these animals to climb onto for safety from larger animals and to get away from quick hand and body movements from people that scare the animals. Small animals also are attracted to bright colours due to their curious nature. When they are out of their cage, they like to crawl into covered places like tunnels to hide and rest. Often they climb inside a person's clothes, and sometimes fearfully bite or accidentally claw a person trying to put them back in their cage. Another problem arises when the animal relives itself, which is quite often if the animal is afraid or uncomfortable. The droppings of small animals are not excessively large and generally dry quickly without much noticeable odor, but it may stain or discolour clothing. It is not uncommon for a person to have to change clothing after handling small animals.

[0008] A number of shoulder drapes with perches for birds have been developed, most inclined to locate over ones shoulder with some form of waist collecting receptacle. Although these have been suitable for birds, they have no tunnelling effect for small animals such as gerbils, mice, lizards, tarantulas, etc., that need to be more sheltered and confined, both for the safety of the animal and its comfort as it is being transported. There are several devices for mazes and tunnels available to transport small animals and to provide tunnels and mazes: however, they are not made of flexible material, nor do they fit around the shoulders of the owner.

[0009] U.S. Pat. No. 5,054,427 of Hoover describes insertable stacking components which are transparent to view the animal and the configuration of the maze pieces can be changed for more entertainment of the animal. They are made of transparent, colored, molded plastic and are meant to be in an enclosure such as a cage: therefore they are not suitable for safe enclosure of the animal while it is being transported and the animal can't be placed on the owners body. U.S. Pat. No. 4,542,713 of Hansen makes available a kit for making your own maze, but the invention is designed for school project uses and is too cumbersome to be portable when completed.

[0010] U.S. Pat. No. 6,516,745 of Spires describes a pet travelling kit that resembles a folding garment bag. It provides a cushion for the pet and pockets for storing items the pet may need: however, it is designed for a cat or dog and would not be suitable for the smaller animals such as gerbils, mice, lizards, snakes, etc., because it is too big and it would be hard to find such a small animal to remove or check on during travel without the possibility of the animal slipping away.

[0011] U.S. Pat. No. 5,275,125 of Rotramel describes an animal harborage which is made primarily as a pest trap in which you can inject insecticides. Although it would be a suitable container for insects because it has artificial webs and is made of solid porous materials, it is designed as a cage in which the insects could hide, thus it would limit the best observation of the insect or rodent, and would not allow the close feeling an owner gets when the pet is placed on the shoulder.

[0012] U.S. Pat. No. 6,450,126 of Schellenbach describes a shoulder draped bird perch which transports birds on both shoulders of the owner and allows for adjustable fasteners, weighting of the material,

attachment of toys and adjustable sizes. While it is quite adequate for all sizes of birds who are trained to stay on an owners shoulder, it does not have any tunnels for small animals which need to be confined while being observed, displayed, trained and transported.

[0013] There is such a pressing need in the field of garment design for new shoulder worn devices to provide a secure environment for owners to display, entertain and transport their small animals. This garment has been designed with unique features to show off, entertain, observe, and transport small animals along with protecting the wearer's clothing from being soiled by animal droppings.

BRIEF SUMMARY OF THE INVENTION

[0014] The above noted problems, and others, are over come by the small animal shoulder carrier garment of this invention, which basically covers the front and back shoulder areas of the wearer, opening at the front with any one of a number of conventional means. The releasable fasteners allow the adjustment of the tunnel configuration and for easy removal of the animals, making it possible to remove said animal from any point along the garment edges. The ties provide a means where by toys and other paraphernalia are attached to the garment. It is foreseen that some people will enjoy covering both the top layer and the bottom layer of the tunnels with toys, bells, mirrors and buttons along with any other items a small animal would play with in the tunnels or which they wish to display. These garments, as in all garments, will be made in varying sizes; small, medium and large.

[0015] While any suitable configuration for the garment may suffice, the preferred design will incorporate a top panel and bottom panel which are attached by releasable fasteners that provide a tunnel, an enclosed environment for the animal, the attachment of other toys in the tunnel and allow for the laundering of the garment. The top and bottom panels are attached to each other by the conventional method of sewing at the neck opening. The outer edges of the top and bottom panels will be attached to each other with, but not limited to, a hook-loop type of attachment to allow for easy laundering of the garment and easy removal of the animal. The rear of the garment will cover the area midway down the back, and outwardly just past the break in the shoulders with angles corners at the lower extremities. Two frontal panels, a left frontal panel and a right frontal panel, are extensions of the back panel, formed by the neck opening in the garment and are attached to each other with, but not limited to, a hook-loop type of attachment, and overlapping in the front, as in any shirt or blouse type of garment with, but not limited to, a hook-loop type of attachment with the hook-loop attachment slight adjustments may be made for the varying sizes of the wearer, while with buttons, snaps and other conventional means of attachment there are similar adjustment capabilities, but all will work for the closure of the two frontal panels of the unique garment as well as the outside edges, according to the type of animals being transported. These frontal panels will cover the upper chest area of the wearer from the apex of the shoulder to approximately {fraction (2/3)} of the way down the chest, depending on the size of the wearer. The frontal panels will have an angled configuration matching those of the rear panel. The neck line of the garment may have any number of styles, V neck, square neck, or a curved neck line, giving a variety of styles while staying in the scope of the patent, the material for the bottom panel of the preferred embodiment would be, but not limited to, 100% cotton, where by it would be easily laundered, and available in a wide variety of bright and unique colors and patterns. This type of material would absorb the moisture and the bright colors would conceal some of the droppings. The droppings of small animals are often a white substance that when dry can be brushed off easily. A nonsliding material as in, but not limited to, a soft cotton flannel, will be used for the backing of the bottom panel to prevent slipping with the movement of the animal. The material for the top panel of the preferred embodiment would be, but not limited to, a see-through, mesh material such as fiberglass screening, fisherman's netting, etc., whereby the garment could be easily laundered, and available in a wide variety of mesh hole sizes for various sized animals, reptiles and insects. This type of material allows the animal to be easily observed, provide adequate air circulation and confine it while being transported or displayed.

[0016] The ties will be used to attach toys, and other paraphernalia for entertaining the animals and making the garment more fun to wear. The panels may be turned inside out and sewn in a conventional manner for assembly, or may be edges with a colorful bias tape, which is another conventional method for manufacturing garments. It must be noted that, like adding toys to the inside of an animals cage and adding pins to a funny hat, this garment is intended to be adorned in a number of ways by the wearer, but the adding of tunnels are included within the scope of this patent.

[0017] It is the object of this invention to create a garment whereby the wearer can transport varying sizes of small animals, reptiles and insects in a relatively natural environment.

[0018] It is also the object of the invention to create a device which protects the wearers clothing, both front and back, from damage from a small pet's droppings when transporting on the shoulder, or damage from the pet's teeth and claws.

[0019] It is another object of the invention to create a device which creates a tunnel enclosure and carrier garment for transporting, training, displaying and observing small animals, reptiles and insects.

[0020] It is still another object of this invention to create a garment that may be made of a wide variety of bright and colourful materials enhancing and showing off the color of the pet animals.

[0021] It is still another object of this invention to create a garment that may be made in varying sizes while being able to adjust within each size to make the garment fit comfortably to accommodate the movement of the animal.

[0022] It is yet another object of this invention to create a garment that can be easily adorned with toys and other paraphernalia inside the tunnels to entertain the animal and to enhance the garment. The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts that will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0023] FIG. 1 is a frontal perspective view of the PetBib shoulder carrier garment device with a mesh see-through top panel and a bottom colorful panel joined together with releasable fasteners and ties. The cut-a-way in the right front panel shows the fasteners that create the tunnels and an example of the typical shiny gemlike toys and ornaments that are placed strategically throughout the tunnels created by the joining of the top and bottom panels.

[0024] FIG. 2 is a rear perspective view of the PetBib shoulder carrier garment device with the mesh see-through top panel and the bottom colorful panel joined together with releasable fasteners and ties. The cut-a-way in the rear view shows a typical small animal in the tunnels with strategically placed typical nesting and the releasable fasteners, which create the tunnels.

DETAILED DESCRIPTION

[0025] FIG. 1 is a frontal perspective view of the PetBib shoulder carrier garment device 8 displaying a first panel depicted as a right frontal panel 12 and a second panel shown as the left frontal panel 14. The right frontal panel 12 is folded back displaying an optional means of attachment of the right frontal panel 12 to the left frontal panel 14 mating fasteners in the form of hook material 16 and loop material 18 attached to the garment device 8 by means of sewing, adhesive, or other conventional means of

affixing of the fastener to the fabric of the garment device 8. Of course, the means of attachment of the first panel to the second could be conventional fasteners such as snaps, hooks and eyes, or ties, but the current best mode features hook and loop fabric.

[0026] The front neckline 31 of the garment device 8 will be available in a number of variations of style, V neck, a square neck, or curved neck, with a back neckline 30 retaining the conventional curved configuration. The lower extremities 22 and 24 of the frontal panels 12 and 14 in the current best mode have the angled configuration displayed in FIG. 1, but other shapes are anticipated.

[0027] The back panel 30 having the similar angled extremities 22 and 24 in the current best mode with the most stable mount extends approximately two-thirds of the way down the back of the wearer, depending on their size. Of course different owners may wish to have this extension down the back larger or smaller, and styles may dictate a change also, and such is anticipated.

[0028] The backing or inner surface 38 of the garment device 8 is currently best constructed of a soft flannel material; however, other materials could be used depending on the wearer's comfort concerns. The edges 33 of the garment device 8 are configured in any convention manner, one current mode being the turning of the garment device 8 inside-out and sewing the edges 33, or edging the garment device 8 with a conventional bias tape.

[0029] A typical pet small animal 10 resting on the bottom panel 66 in FIG. 2 has the high probability of placing droppings 88 displayed on the bottom panel 66 during the animal 10's daily tenure on the device 8. Since the device functions as a means for protection of the clothing of the user from such droppings, material resistant and from which the droppings may be easily removed is used for the bottom panel 66.

[0030] A toy 68 is shown attached on the bottom panel 66 on the tunnel floor in FIG. 1, although they may be attached to any of the tie straps 20 throughout the article. A means to entertain the animal 10 is thus provided by attachment of the toy 68 to the device 8 and the device 8 can be provided with a plurality of such toys 68 that are releasably attachable to device 8 to enhance this means to entertain the animal 10.

[0031] Additional function is provided by a means to traverse through tunnels 52 on opposing shoulders of the user, without touching the user. This means to traverse between shoulders is provided by the tunnels 52 which allows the animal 10 to translate between the two shoulders 42 by travelling through the tunnels 52 as it goes from one side to the other. Of course other types of fabric or material can be used to form the tunnels 52 but the current best mode features see-through, mesh materials as they provide an excellent shelter construction for the animal 10 during traverse and to provide adequate air supply. This encourages the animal 10 to traverse between shoulders without touching the user's back, neck, or clothing, and to change positions, thus allowing the animal 10 more exercise as well as dispersing the animal's weight on the user to two shoulders over time. Nesting material 48 can be placed in tunnels 52 as shown in the cut-a-way of FIG. 2.

[0032] While all the fundamental characteristics and features of the PetBib shoulder carrier garment device 8 have been shown and described, it should be understood that various substitutions, modifications and variations may be made by those skilled in the art without departing from the spirit or scope of the invention. Consequently, all such modifications and variations are included within the scope of the invention as defined by the following claims.

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